Bob's TechTalk #34
by Bob Eckweiler, AF6C

Current Sources:

We're moving along on our deluxe code practice oscillator. The phase shift oscillator is up and running at 1,000 Hz, and you know how to change the frequency if you prefer a different tone. We also know how to buffer the oscillator so it will continue to oscillate when a load is applied. Now all we need to do is design a way to key the oscillator, adjust the volume and add an amplifier capable of driving a speaker. The design I've chosen for the amplifier is rather a new circuit that was developed after the transistor became popular. One of the most expensive and bulky parts of tube audio amplifiers was the output transformer. This continued to be true in early solid-state equipment that used a pair of similar transistors in push-pull driving a speaker through an output transformer. Then a clever design was introduced that utilized complementary transistors, and utilized the emitter follower and a current-mirror. Complementary transistors are transistors that are identical in properties except for polarity; one is type NPN and the other is type PNP. The current-mirror is why we're diverging a bit this month to discuss current sources and the current mirror.

We are familiar with batteries and power supplies (voltage sources) that put out a constant voltage. If you shunt the output with a resistor, (Figure 1A) the current I flowing through the resistor will be governed by Ohm's law:

$$I = \frac{V}{R}$$

where V is the voltage source's voltage and R is the resistor's value in Ohms. Changing the resistor changes the current flowing through the circuit. However, the voltage across the resistor stays constant (within the capability of the voltage source).

A constant current device is shown in Figure 1B. Its symbol is two overlapping circles, As its name implies, it puts out a constant current. If you shunt it with a resistor, the voltage across the resistor will also be governed by Ohm's law:

$$V = I \times R$$

where I is the constant current source's value and R is the resistor's value in Ohms.

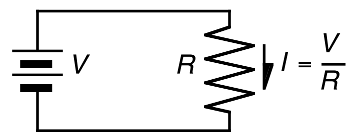

Fig. 1A: A Constant Voltage Source

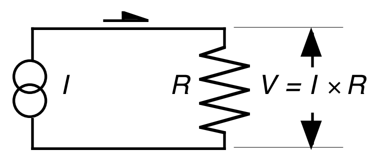

Fig. 1B: A Constant Current Source

When you place a too low a resistance or short across a power source, excessive current flows, the voltage drops and, unless protection is provided, smoke often follows! Obviously batteries and power supplies were not designed for such a condition. A similar thing happens with a constant current source when its output is left open or the resistance across it is very high. Ideally, in this case the voltage rises to a very high level. Practically, however, current sources have a head voltage which is the maximum that they can output. Above that, the current source loses its ability to maintain the constant current. What this says is that just as a power supply is rated for a maximum current, a constant current source is rated for a maximum voltage.

A well designed battery or voltage source has a low impedance (series resistance). This is the resistance that causes the voltage to drop on a power supply as more current is drawn. A current source is just the opposite. It has a high impedance (series resistance) that acts to keep the current constant with changes in voltage.

Some Practical Circuits:

Figure 2A is a circuit of a simple constant current source used in older vacuum tube equipment where high voltages are available. It is just a voltage source V_S with a large series resistor R_S. If the circuit resistance R_c is small compared with R_S, the current change with changing R_c will be small too, and the current will remain nearly constant. This scheme is often used in biasing of DC vacuum tube amplifiers, and developing linear sawtooth waves for oscilloscopes.

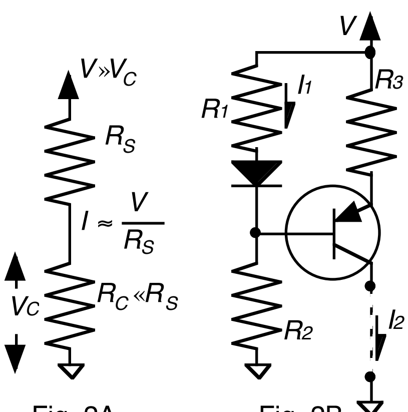

Fig. 2A Fig. 2B
Constant Current Circuits

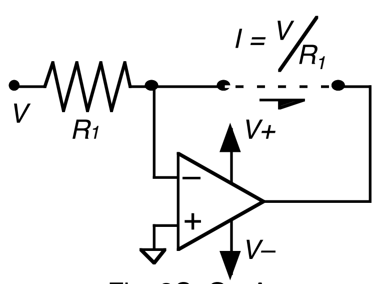

Fig. 2C: Op-Amp Current Source

A more complicated current source is shown in Figure 2B. Assuming that the voltage drop across the diode and base-emitter junction of the transistor V_{BE} are equal, then the voltage across R_1 and R_3 must be equal. The current I_1 through R_1 is:

$$I_1 = \frac{V - V_{BE}}{\left(R_1 + R_2 + \frac{R_2}{\beta}\right)} \approx \frac{V}{(R_1 + R_2)}$$

If ß is large, we can ignore the term with ß in it; also if V » V_{BE} we can also ignore V_{BE} as shown above. (For silicon transistors, V_{BE} is on the order of 0.6 to 0.7 volts.) Since we want to keep the current source's head voltage as high as possible R_1 and R_3 should be chosen to drop only a small part of the source voltage (but, for stability, large with respect to expected changes in the transistor's base-emitter voltage drop with temperature). Since the voltage across R_1 and R_3 are equal, the following ratio holds:

$$V_{R1} = I_1 \times R_1 = V_{R3} = I_2 \times R_3$$

Substituting in the value for I1 gives:

$$I_2 = \frac{V - V_{BE}}{\left(R_1 + R_2 + \frac{R_2}{\beta}\right)} \times \frac{R_1}{R_3}$$

$$\approx \frac{V}{(R_1 + R_2)} \times \frac{R_1}{R_3}$$

This is a neat little circuit if you need a constant current. It is often used to produce a voltage that increases (ramps) at a constant value by using the constant current to linearly charge a capacitor. It is easy to breadboard and play with.

Current Devices:

A simpler (but more expensive) way to produce a constant current is to use one of the solid-state devices on the market. Operational amplifiers (like the 741 and my favorite the TL080 series) make really simple and accurate current sources that are bipolar. Figure 2C shows the simple circuit. Current regulator diodes are also available at various specified currents. The 1N5283 – 1N5314 series contain 32 types with nominal current values of 220µA to 2.7mA. They will act as current regulators up to a maximum voltage of 100 V. Figure 3 shows the schematic symbol for a current diode which is similar to a normal diode except the triangle is replaced with a circle. As with a normal diode, the line identifies the cathode.

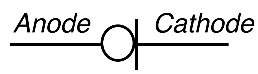

Fig. 3: Symbol for a Current Diode

A Transistor as a Diode:

While discussing the circuit of Figure 2B, I made the assumption that: the that the voltage drop across the diode and base-emitter junction of the transistor V_{BE} are equal. Inside an integrated circuit (I_C) this is typically true; the materials and construction are the same, and the base-emitter junctions are close together and follow each other in temperature. However, with discrete components this assumption may not be true.

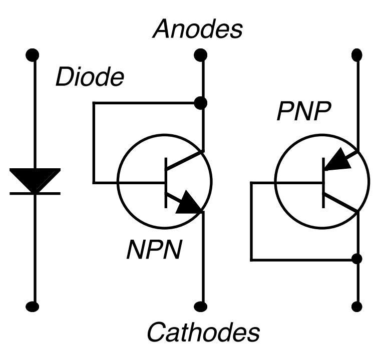

Fig. 4: Transistors Can Be Wired as a Diodes

Diodes and transistors are manufactured with different junction areas and material properties. Unless a well matched junction is chosen, the assumption will be a poor one. Here is a way to make the match closer. Instead of a diode, use a transistor connected as shown in Figure 4. Choose an identical transistor (preferably one from the same manufacturer and even better from the same batch). You now have junctions with closely similar characters. There is one additional thing you need to compensate for. The base-emitter junction voltage changes with temperature. Keep the components close in temperature and don't make one dissipate a lot more power than the other. In some critical circuits these components are mounted physically close together on a heat sink.

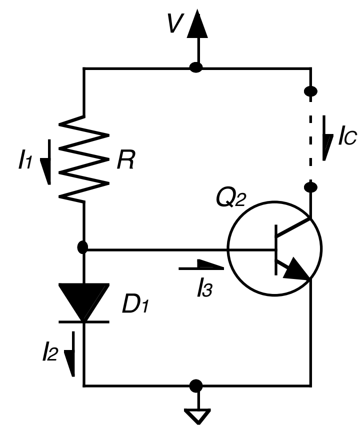

Fig. 5A: The Basic Current Mirror Circuit

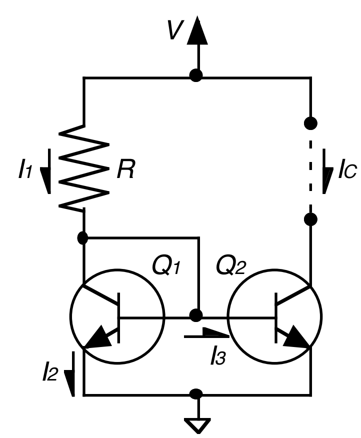

Fig. 5B: The Modified Current Mirror Circuit

The Current Mirror:

Figure 5A shows a basic circuit called a Current Mirror. By adjusting R you can set the current I_1. The current I_C flowing in the collector of the transistor Q_2, will closely mirror I_1 (That is I_C and I_1 will be nearly the same.) This circuit is used in most analog Integrated Circuits to bias stages. For example, the 741 operational amplifier has five current mirrors as part of its design.

For the current mirror to work the junction of diode D_1 and the base-emitter junction of transistor Q_2, must have almost identical properties [See side bar]. If this is the case then the diode current I_2 and the transistor collector current I_C are identical:

$$I_C = I_2$$

At the junction of resistor and the diode it is obvious that:

$$I_1 = I_2 + I_3$$

or: $$I_1 = I_C + I_3$$

Since the base current I_3 is small compared with I_C:

$$I_C \approx I_1$$

The current I_1 is set by R as:

$$I_1 = \frac{V - V_{BE}}{R}$$

And, if V is much greater than V_{BE}:

$$I_1 = \frac{V}{R}$$

Since it may be difficult to find a diode with the right properties, a transistor Q_1, identical to Q_2, is substituted for D_1 as shown in Figure 5B.

In the next TechTalk column we will be using current mirrors to develop a class B amplifier that will drive a small speaker from our oscillator's signal. We will also briefly discuss the difference between class A, B and C amplifiers. Since class D amplifiers and above are digital in design, we'll skip discussing them.

73, from AF6C

This article is based on the TechTalk article that originally appeared in the Month Year issue of RF, the newsletter of the Orange County Amateur Radio Club - W6ZE.